Modification of larch wood by intensive microwave irradiation

LIU Hong-Hai, WANG Qing-Wen*, YANG Lin, JIANG Tao, CAI Ying-Chun
MOE Key Laboratory of Bio-based Material Science and technology, Northeast Forest University, Harbin 150040

Abstract: The larch wood was treated by microwave irradiation under different radiant intensity and treating duration. The microwave-treated wood specimens together with the un-treated for comparison were impregnated by water in pressure vessel and then tested for permeability, mechanical properties and microstructure change by SEM to study the modification performance of microwave treatment on larch wood. The results showed that under suitable conditions of microwave treatment the permeability of larch wood was improved without noticeable decreasing of the modulus of rupture (MOR) and the modulus of elasticity (MOE). The radial parenchyma and some pit membrane were ruptured, and tiny cracks were formed in the cell walls. The formation of tiny cracks in the cell walls serves as man-made channels of gas and liquid and this contribute to improve the permeability of the wood.

Key words: Larch wood; Modification; Microwave irradiation; Permeability
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Introduction

Larch resource is abundant with big volume storage in China. Larch wood has nice characters such as high mechanical strength and hardness, clear, natural and elegant grains. Its market potential is great in the field of furniture and decoration. However, larch wood has certain defects, for instance, difficult to dry, apt to split and distortion as well as the high content of resin which restricts its application in some fields, especially in furniture manufacture. In recent years, with the shortage trend of hardwood species supply, research was focused on the modification of larch wood to apply this wood species to the furniture and decoration industry. According to previous research on the properties of larch wood, the permeability is the key parameter which should be improved for its further application.

Bao and Lu (1992) have pointed out: the main factor of influencing permeability is the radius and number of effective openings on pit membranes. Other researcher's opinion on the reason causing larch wood poor permeability, difficult to dry and apt to split was that the larch wood contains a large amount of resin and gum inside (Chang, 1997).

Larch belongs to coniferous tree, the critical channels where the moisture and the nutriment exchanges are the bordered pits which usually occur on the cell walls of longitudinal tracheid. Larch wood has heartwood characters with narrow sapwood and spacious heart wood. While the heartwood area occupies the majority of the log, the situation of bordered pit on heartwood exerts a tremendous influence to the migration of the moisture during drying period. Relevant research showed that the pit membrane and pit border of heartwood bordered pits, as well as the cell surface are covered with a thin layer non-cellulosic substance which forms a kind of crusting pit membrane, blocking the channels among cells and causing larch timber very poor permeability. One of the ideas to improve the permeability of larch timber is to change cell pits or some cell walls to improve the efficiency of the capillary system for steam transferring. Torgonikov (2000a, 2000b) and Vinden (2000) applied microwave irradiation to treat hardwood with low permeability and found that the permeability was improved.

By applying high intensity microwave irradiation with suitable frequency to larch wood with certain moisture content, the water in the wood cell cavity absorbs the energy and boils off quickly forming high steam pressure which causes cell microstructure change, resulting in the properties change including the permeability. In this paper, larch wood was treated by microwave irradiation under different radiant intensity and treating duration. The microwave treated larch wood specimens and the untreated for comparison were then impregnated with water, tested for mechanical properties and studied by a scanning microscope for microstructure change to evaluate the modification performance of microwave irradiation.

Material and method

Specimen preparation

The larch wood (*Larix Olgensis*) timber, size 60 mm×200-300 mm×4000 mm (longitude), used in this study was sawn from trees grown in the same forested area of Changbai Mountain.

Specimens for microwave treatment were processed from the timber into standard slats with size 300 mm (longitude)× 25 mm×100 mm in the laboratory after shaving and marking, piling them up and then covered with the plastic film to prevent the moisture losing too fast. Because larch timber is highly anisotropic, the matched specimens of one group were made from the same timber, being of the same grain direction, similar density and annual ring thickness.

Apparatus

The resonant cavity microwave drier for timber with 19kW output power was used as the high intensity microwave treatment equipment.

The vacuum-pressure treating cylinder was of Φ300 mm and 350 mm long, equipped with a vacuum pump model CX-8 and an air-compressor model W-0.6/20.

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Biography: LIU Hong-Hai (1975-), male, Graduate, Northeast Forest University, Harbin 150040, P. R. China. Email: seaman_liu@yahoo.com.cn
* Corresponding author: Email: qwwang@public.hr.hl.cn
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Other apparatuses were a thermostatic electric heating air-drying drier model DHG-9140A, a low vacuum scanning electron microscope model JSM-5610KV, and a computer controlled universal mechanical testing machine model RGT-20A.

Original moisture content determination

Original moisture content of specimens were determined by oven-drying method with error of ±1%.

Microwave treatment

Matched specimens with similar moisture content 24.5% (deviation within 5%) were treated by microwave of different intensity (by output power). The treating process was divided into two phases. In the first phase the microwave power was lower, while in the second phase the treating power was higher or the same as in the first phase. Between the two phases there was a 25 to 30 seconds time for the temperature of the wood specimens to be equilibrium. The treating power schedule was 5kw/5kW, 5kW/7kW, 5kW/9kW, 7kW/7kW and 9kW/9kW, respectively. The treating duration schedule was 20s/20s, 20s/30s, 30s/30s and 30s/50s, respectively.

Impregnation of wood specimens

After weighing the wood specimens, put the treated specimens and the untreated control in the treating cylinder, made sure each specimen were kept apart from other specimens by glass rods. After the cylinder was vacuumed to a vacuum of -0.09MPa and maintained for 10 min, distilled water was introduced into the cylinder under vacuum, and the cylinder was pressurized by the air-compressor to a pressure of 1.0MPa and keep this pressure for 3min, and then released the pressure, unloading the specimens, weighing the treated specimens after cleaning the surface water. The whole process was carried out at room temperature. The permeability of the wood specimen was evaluated by its Weight Increasing Rate (WIR), which is calculated according to the following equation:

WIR (%) = 100× (weight after impregnation – weight before impregnation treating) / weight before impregnation

Mechanical properties Test

After impregnation the microwave-treated and untreated wood specimens were air-dried to moisture content of 12%, balanced at 23℃ and 60%RH for one week, and then processed into specimens of the size 150 mm (longitude) × 15 mm (radial) × 5mm(tangential) for bending test.

Results and discussion

Permeability of microwave-treated larch wood

Our preliminary study on the permeability of larch wood by microwave modification showed that the moisture content and density of wood, the microwave intensity and microwave treating duration were the key factors for the treating performance (Yang, 2004). In this paper, it was found that not only the microwave intensity itself but also its applied schedule and the treating time schedule had remarkably influence on treating performance. Fig.1 to 3 is some of the examples showing the relationship between the permeability and treating factors (microwave power, treating time, and their schedule).

Weight increasing rate (WIR) of microwave-treated wood specimens was higher than un-treated wood, and increased with increasing microwave power (Fig.1). Compared to using the same microwave power schedule in the two-phases microwave-treating, remarkable increase in WIR was observed when using two different microwave power and the best power schedule in this paper was 5kW/9kW, even better than 9kW/9kW power schedule. In order to improve the permeability of wood, it was necessary to treat the wood with intensive microwave irradiation. However, it was not the case that the more intensive microwave the better permeability of the wood, especially in the first treating phase. In the first treating phase, lower microwave power was in favor of wood specimen to be heated more evenly and this was important for the water to gasify quickly and evenly. Too intensive microwave irradiation in the first treating phase caused earlier gasification of water because of the uneven heating of the wood, and this decreased the effective gasification of water in the second phase. Therefore, the pre-treatment of wood by lower microwave power then the treatment by higher microwave irradiation improved its permeability more effectively.

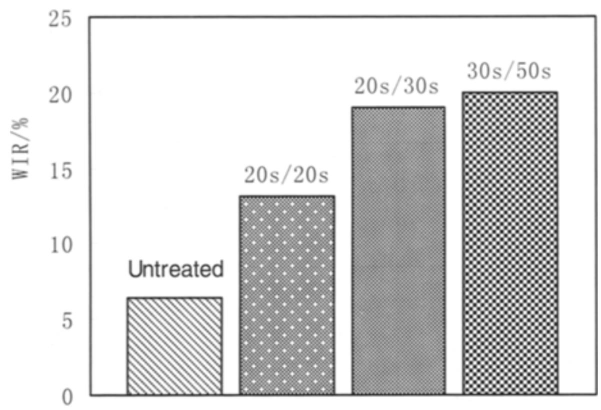

Fig. 1 Weight increasing rate (WIR) of larch wood treated by different microwave power

Notes: The treating duration for all of the specimens was the same 30s/30s.

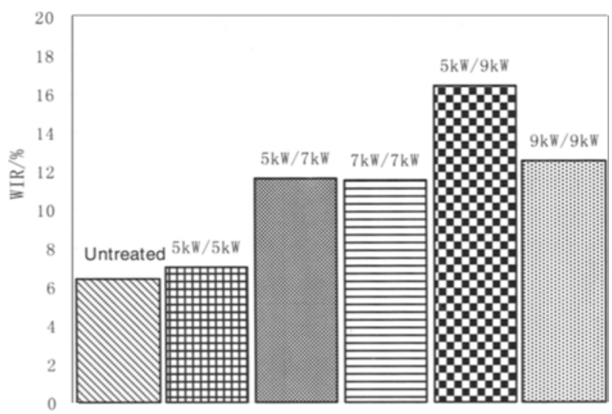

Fig. 2 Weight increasing rate (WIR) of larch wood treated by different treating duration with 5kW/9kW microwave powers

Treating duration had much influence on the permeability of larch wood, especially for the power schedule of lower power in

the first phase and higher power in the second phase (Fig. 2 and Fig. 3). Using suitable microwave power, such as 5kW/9kW in Fig. 2, the WIR of wood specimen reached a relatively high value when the treating duration increased to 30s/50s. However, experiments showed that the wood cracked visually when using longer treating duration for the 5kW/9kW power schedule. For the more intensive 9kW/9kW power schedule, 30s/30s treating duration schedule was proved to be too long, and in this case the 20s/30s was better (Fig. 3). In Fig.3, the WIR value of longer treating duration schedule 30s/30s was not as high as the shorter treating duration schedule 20s/30s, this might be due to the uneven- and over-preheating of the wood specimen, the later would diminish the gasification of water and the vapor pressure in the second treating phase, resulting in lower permeability of the wood.

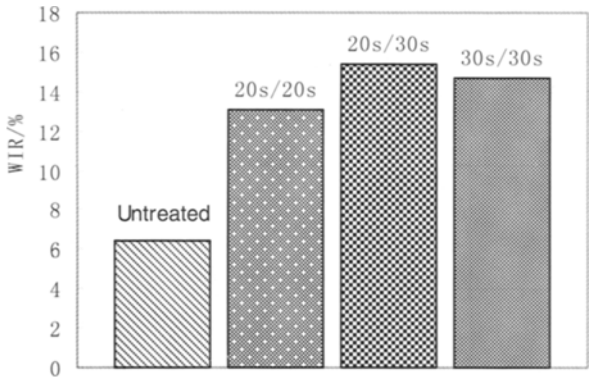

Fig. 3 Weight increasing rate (WIR) of larch wood treated by different treating duration with 9kW/9kW microwave power

When microwave irradiation power is too low to form enough steam to destroy parenchyma and crisp areas on cells, the permeability improvement of the wood is not significant. While treating wood by higher irradiation to improve its permeability considerably, unfavorable effects might develop sometimes by using too high irradiation and too long treating time, e.g. internal crack, ring crack and surface checks.

The micro-structure of microwave-treated larch wood

As a larch wood specimen was subject to micro- wave irradiation, the whole thickness, from surface to internal center, of the wood was heated at the same time. The moisture inside the wood cells vaporized quickly, formed steam impacting cell walls and resulted in fracture of weak areas such as pit membranes (Fig. 4) and parenchyma. In the later case tiny cracks occurred on the radial sections (Fig. 5). The fracture degree is relevant to the treating duration and the microwave irradiation intensity. The longer the treating duration or the more intensive the microwave irradiation or both, the severer the fracture was.

These tiny cracks can be the channel for such fluids as water, vapor, etc. and the permeability of the wood is thus improved. This creates the better condition for the further treatment of larch wood by treating solutions such as fire-retardants, preservatives and unsaturated polyester or other synthetic resin solutions. On the other hand, the formation of these cracks may contribute to release the growth stress of larch timber, reducing checks and warp while drying.

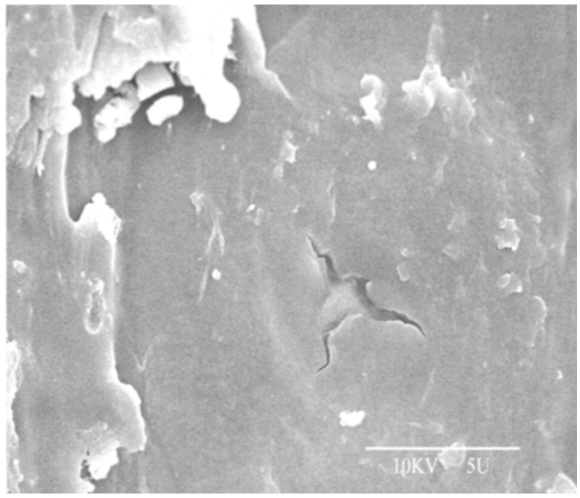

Fig. 4 The broken pit of earlywood of microwave-treated Larch wood

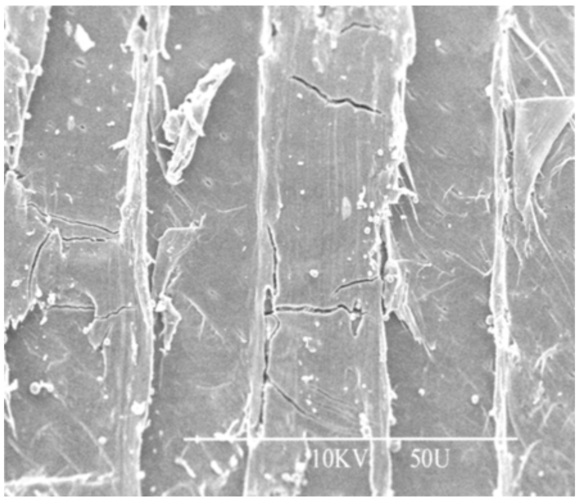

Fig. 5 Tiny checks in the radial section of microwave treated larch wood

The influence of microwave treatment on the mechanical properties of wood specimens treated

Due to pit breaks and the extreme tiny cracks occurred in the thin walled cell, the mechanical properties may decrease a certain degree. Therefore, when optimizing the treating conditions care must be taken of not only the critical parameters of permeability but also of the mechanical properties of the wood.

It can be seen from Table 1 that the modulus of rupture (MOR) and modulus of elasticity (MOE) of the microwave-treated specimens decreased slightly compared to the untreated specimen but not remarkably. This indicates that the tiny cracks on the cell walls, especially on parenchyma which not causing the specimens' appearance changing, did not weaken the macroscopic mechanical properties obviously. The reason for this was maybe the tiny cracks did not connect each other to form macroscopic cracks which have great influence on the mechanical properties of the wood. These tiny cracks released the growth stress inside the wood, which may improve the impact property of larch wood, and this will be reported in later report.

Table 1. Modulus of rupture (MOR) and modulus of elasticity (MOE) of the microwave-treated larch wood by 5kW/9kW

Treating duration /s	20s/20s		20s/30s		30s/30s		30s/50s	
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated
MOR, (MPa)	97.55	85.71	96.45	96.63	109.33	132.99	126.41	116.36
Standard deviation of MOR, (%)	6.53	5.00	9.19	10.42	12.05	12.06	2.54	5.44
MOE, (GPa)	8.67	7.41	7.97	7.65	10.10	11.17	10.85	9.84
Standard deviation of MOE, (%)	0.92	0.48	0.69	1.06	1.05	1.37	0.43	0.55

Conclusions

Microwave irradiation treatment of larch wood broke certain pit membranes and parenchyma of larch wood forming new channel for liquid and gas transfer inside the wood. This resulted in the permeability improvement of larch wood. The effects of microwave treatment were closely related to microwave irradiation intensity (or microwave power), microwave treating duration and moisture content of the wood. For larch wood with moisture content of about 25%, the treating schedule of 5kW for 30sec, then 25sec to 30sec equilibrium, and then 9 kW for 50sec gave the best permeability and mechanical properties. Under proper treating conditions, the microwave-treated larch wood acquired improved permeability while basically keeping its mechanical properties.

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